Sondes/Tests de Gravité
Combination RSD/WL

Workshop OCEVU
Dark Energy: Beyond 6 parameters

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Current situation

So far, no deviation to ΛCDM has been found greater than the statistical errors

Currently, ΛCDM is sufficient to reproduce the background expansion.

Elusive components Dark matter (since the 70's) and Dark energy (since 00's) might signal actual limitations to GR

Parametrized Post Friedman (PPF) Formalism

Hu&Sawicki 2007

Modification of gravity is viewed in terms of an additional "dark energy" stress tensor

$$T_e^{\mu\nu} \equiv \frac{1}{8\pi G} G^{\mu\nu} - T_m^{\mu\nu}$$

After some calculations, we obtain the metric

$$ds^2 = (1 + 2\Psi)\, dt^2 - a^2(t)\,(1 - 2\Phi)\, d\boldsymbol{x}^2$$

In Fourier Space

$$k^2 \Phi_{GR} = -4\pi G a^2 \bar{\rho}\delta$$

$$k^2 \left(\Psi_{\rm GR} + \Phi_{\rm GR}\right) = -8\pi G a^2 \bar{\rho}\delta$$

A parametrization of modified gravity

Zhao et al. 2010, Song et al. 2010, Simpson et al. 2012

- Typically the perturbations to GR are parametrized as

$$\begin{aligned} k^2\Psi &= -4\pi G a^2 \mu(k,a)\rho\delta, \\ k^2(\Phi - \Psi) &= 8\pi G a^2 \Sigma(k,a)\rho\delta, \end{aligned}$$

- In which μ and Σ are function 2 constants

$$\Sigma = 1 + \Sigma_s a^s, \quad \mu = 1 + \mu_s a^s$$

with a linear s=1 or a cubic s=3 dependence on the scale factor

Weak lensing observables

Simpson et al. 2012

- The 2 points auto-correlation functions is defined as

$$\xi_\pm(\theta) := \langle \gamma_t \gamma_t \rangle \pm \langle \gamma_\times \gamma_\times \rangle = \frac{1}{2\pi} \int_0^\infty \mathrm{d}\ell \, \ell \, P_\kappa(\ell) \, J_{0,4}(\ell\theta),$$

- And the convergence power spectrum is

$$P_\kappa^{i,j}(\ell) = \frac{9}{4}\Omega_m^2 \left(\frac{H_0}{c}\right)^4 \int_0^\infty \frac{g_i(\chi) g_j(\chi)}{a^2(\chi)} P_\delta \left(\frac{\ell}{f_K(\chi)}, \chi\right)$$

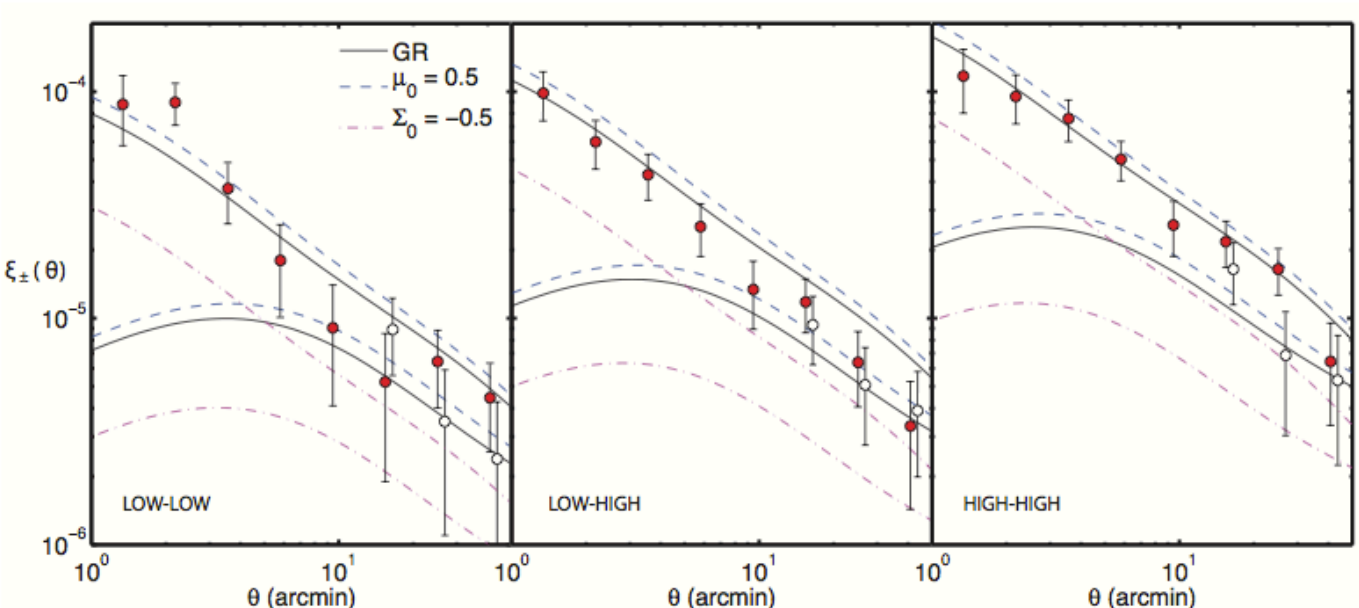
where $P_{\delta\delta} = <\delta(\mathbf{k})\delta(\mathbf{k})>$ is the matter power spectrum, and g_i is a ratio of diameter angular distances

$$g_i(\chi) = \int_\chi^\infty \mathrm{d}\chi' n_i(\chi') \frac{f_K(\chi' - \chi)}{f_K(\chi')}$$

Lensing from CFHTLens

Simpson et al. 2012

- Measurements in CFHTLens (154deg^2 effective)
- 2 bins: $0.5 < z < 0.85$ and $0.85 < z < 1.3$
- Remove small scales in ξ^- because too sensitive to small scale modes in the P_κ



Peculiar velocities

The redshift space cross-power spectrum

$$P_{g\theta} \equiv -\langle \delta_g(\mathbf{k})\theta(-\mathbf{k})\rangle$$

can be infered from PV. In the linear regime the velocity field is proportional to the density field

$$\theta = -\beta\delta = -f\,\delta\,/\,b = -f\,\delta\,/\,(\sigma^2_{8g}/\sigma^2_{8m})$$

where *b* is the linear bias of the galaxy population and

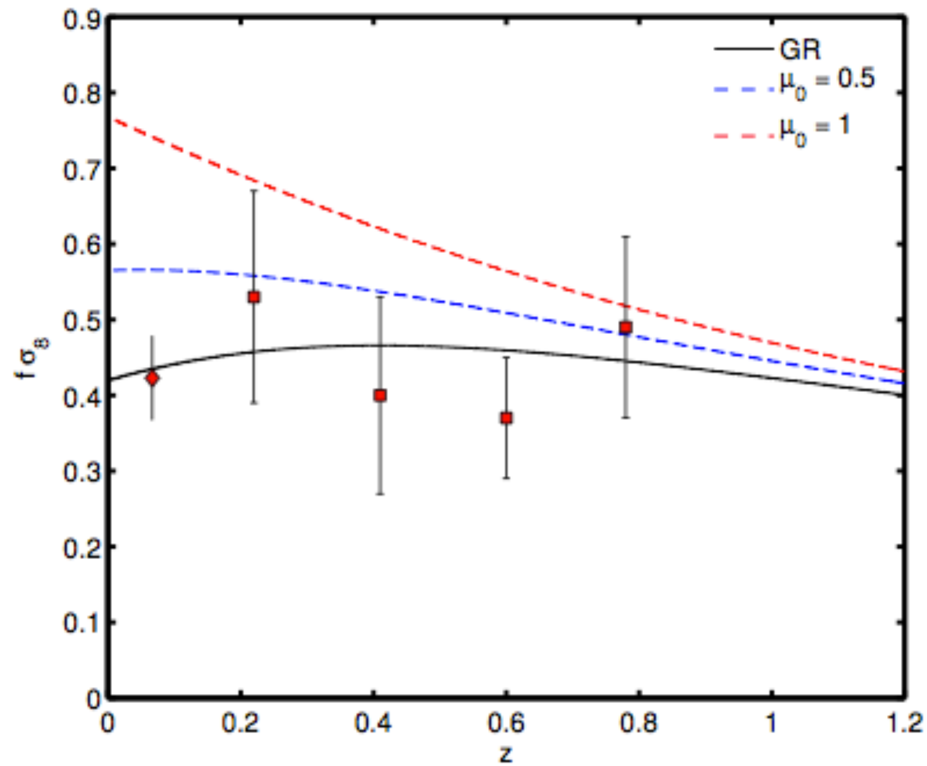
$$f = d \ln D/d \ln a$$

Is the **rate** of the growth factor *D*

Peculiar Velocities from WiggleZ and 6dFGS

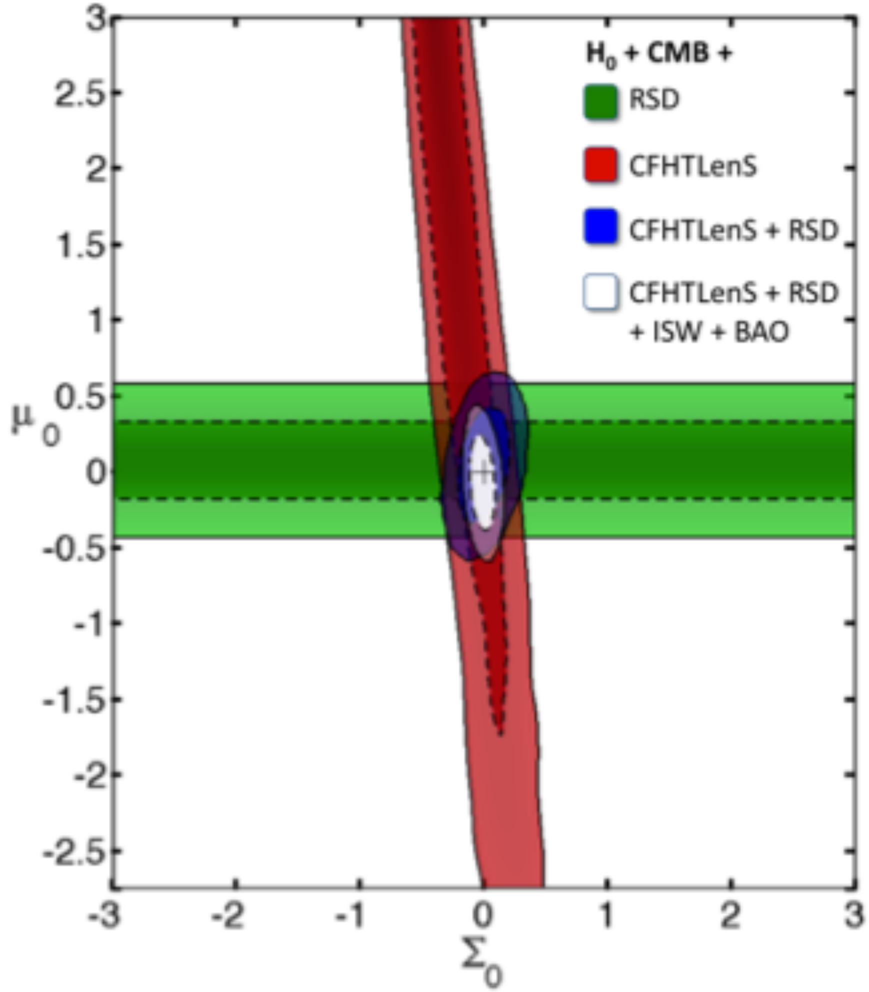
Simpson et al. 2012

- WiggleZ data
  - 151,117 UV and optically selected galaxies in the redshift range $0.1 < z < 0.9$ over $800 deg^2$
- 6dfGS data
  - 125,000 K-band selected galaxies ($8.75<K<12.75$) over the entire southern sky



Joint fit WL+PV

Simpson et al. 2012



The E_G estimator

Simpson et al. 2012, Reyes et al. 2010, Zhang et al 2007

- The E_G estimator is sensitive both to lensing and the growth rate

$$E_G \equiv \frac{\nabla^2(\Phi + \Psi)}{3H_0^2(1+z)\beta\delta}$$

- It can be related to theory through

$$E_G \simeq \frac{\Omega_m\left[1 + \Sigma(\bar{z})\right]}{f(\bar{z})}$$

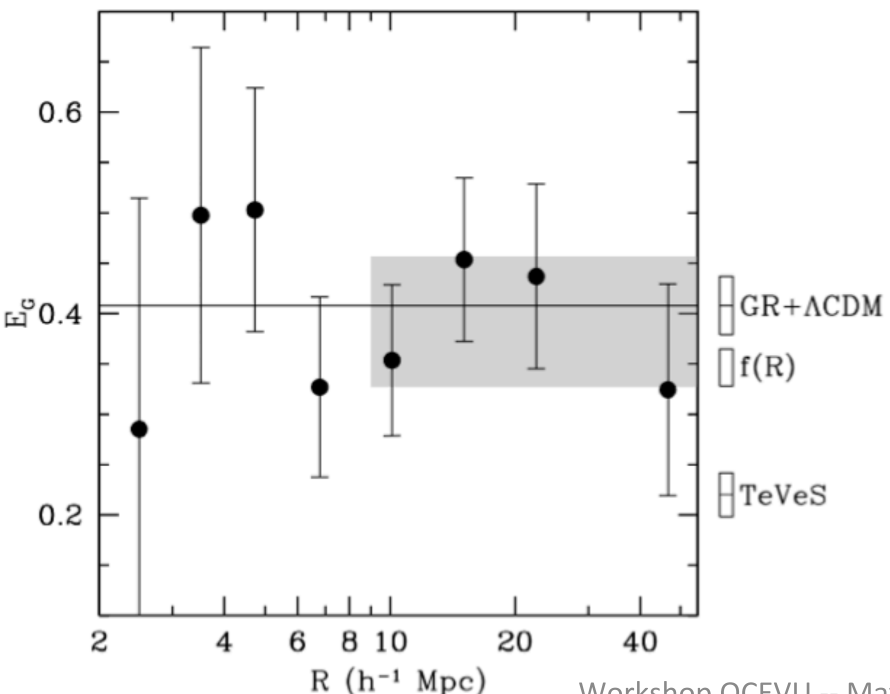
E_G measurements

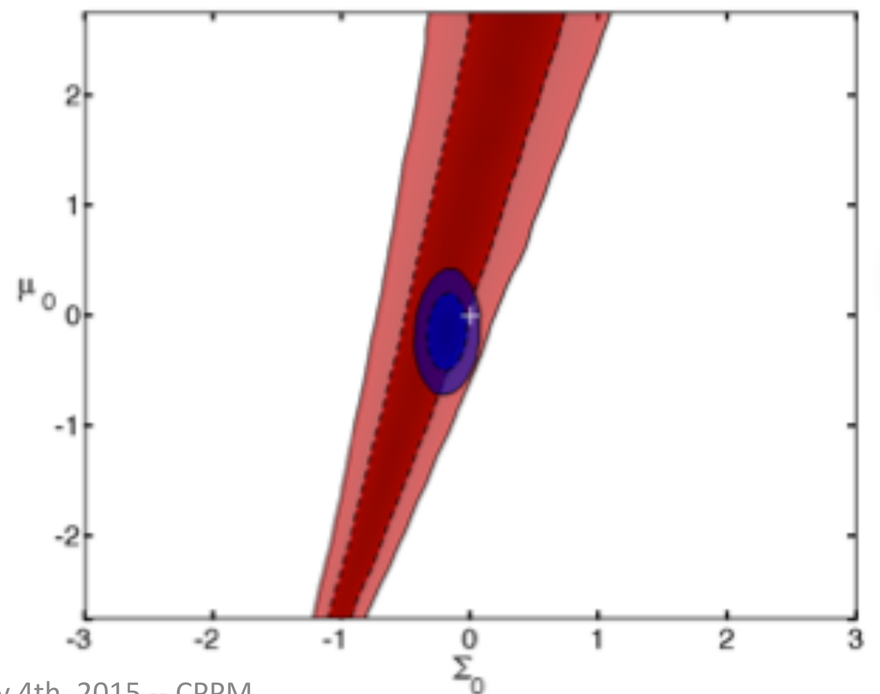
Simpson et al. 2012, Reyes et al. 2010

E_G measured from :

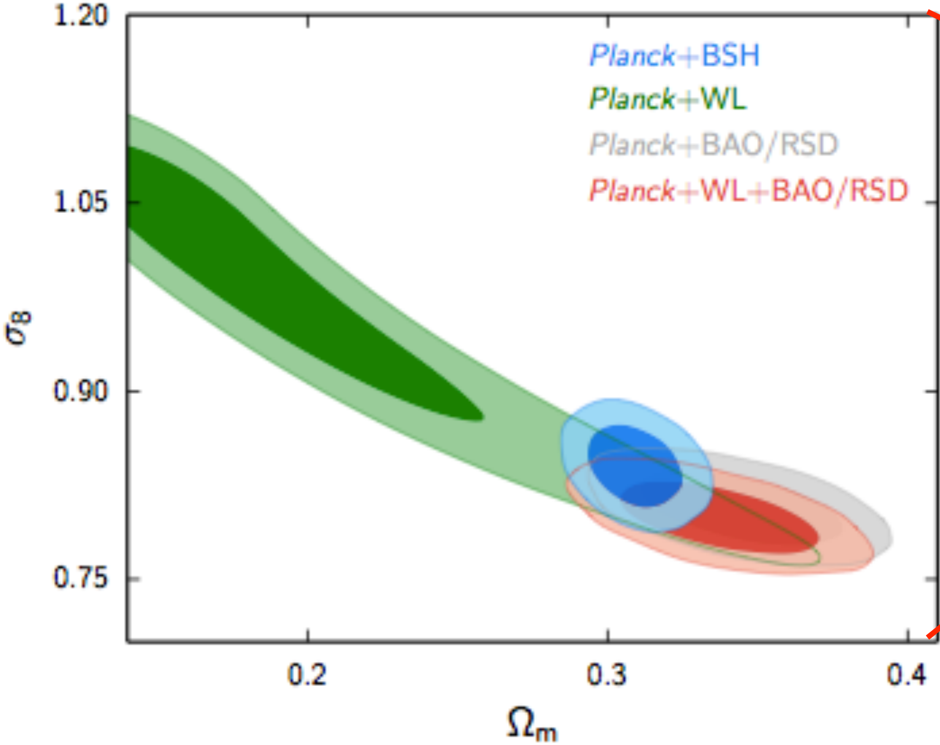
- 70,205 LRGs over 5215 deg^2 in the redshift 0.16 < z < 0.47
- Lensing from 30 million SDSS sources z ~ 0.3

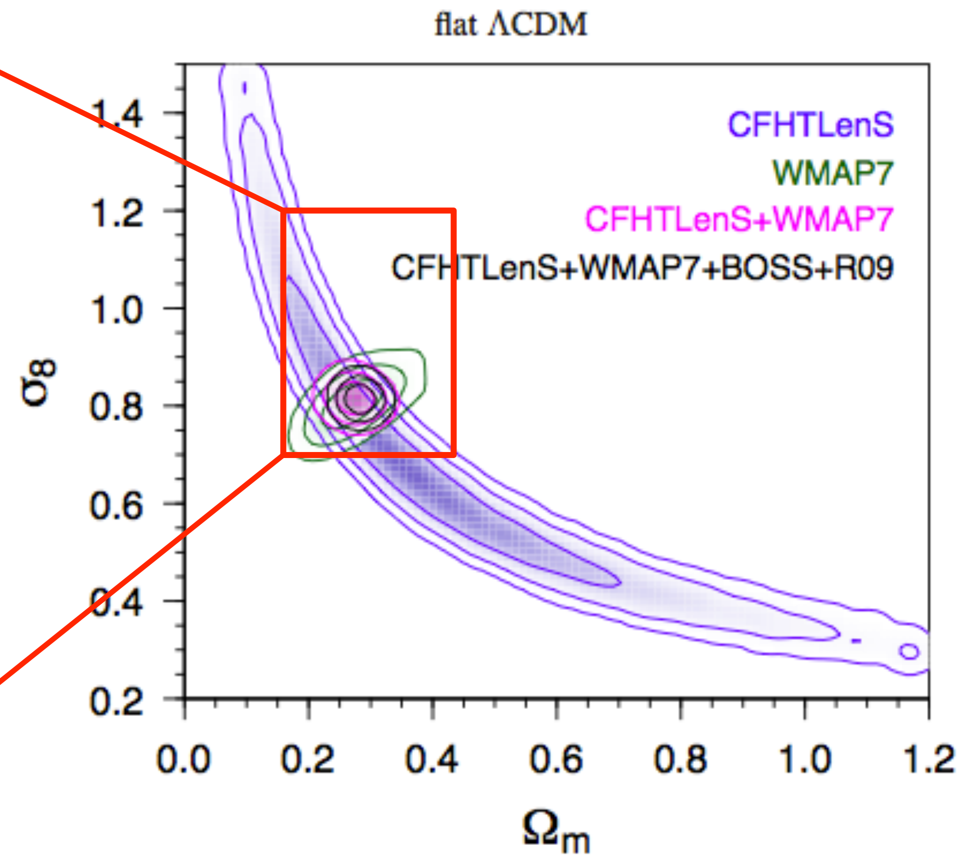
$$E_G(z = 0.32) = 0.392 \pm 0.065$$





Planck results and Tension





Planck 2015

Stringent cuts to keep $\Delta\chi^2 = |\chi^2_{lin}-\chi^2_{nl}| < 1$

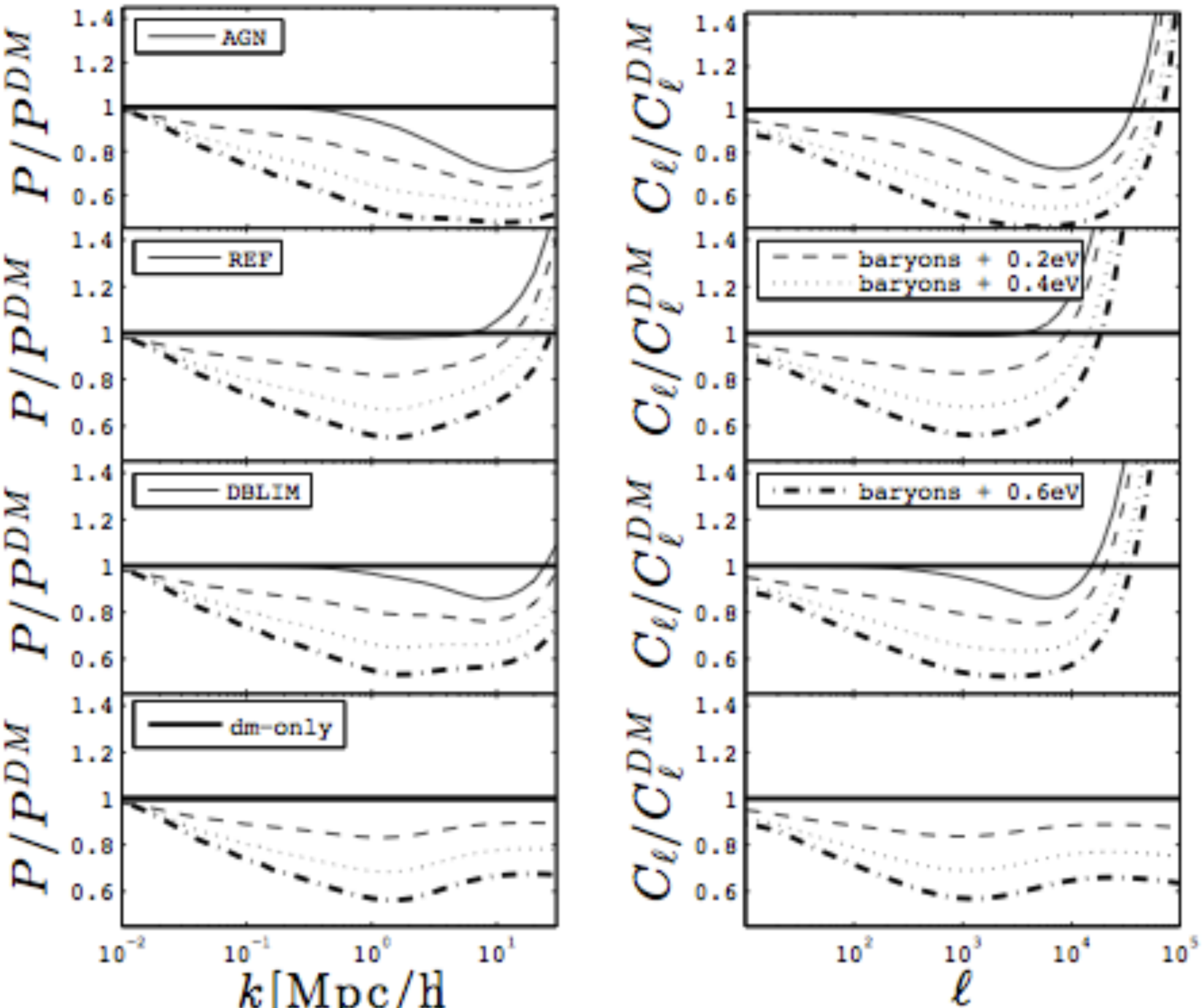
- Remove ξ^-
- Exclude $\theta < 17'$ for ξ^+

Kilbinger et al. 2013

Also cut at $\theta < 17'$ to keep non-linear Halofit predictions of ξ^+ within 5% of the linear model

Bias at small scales?

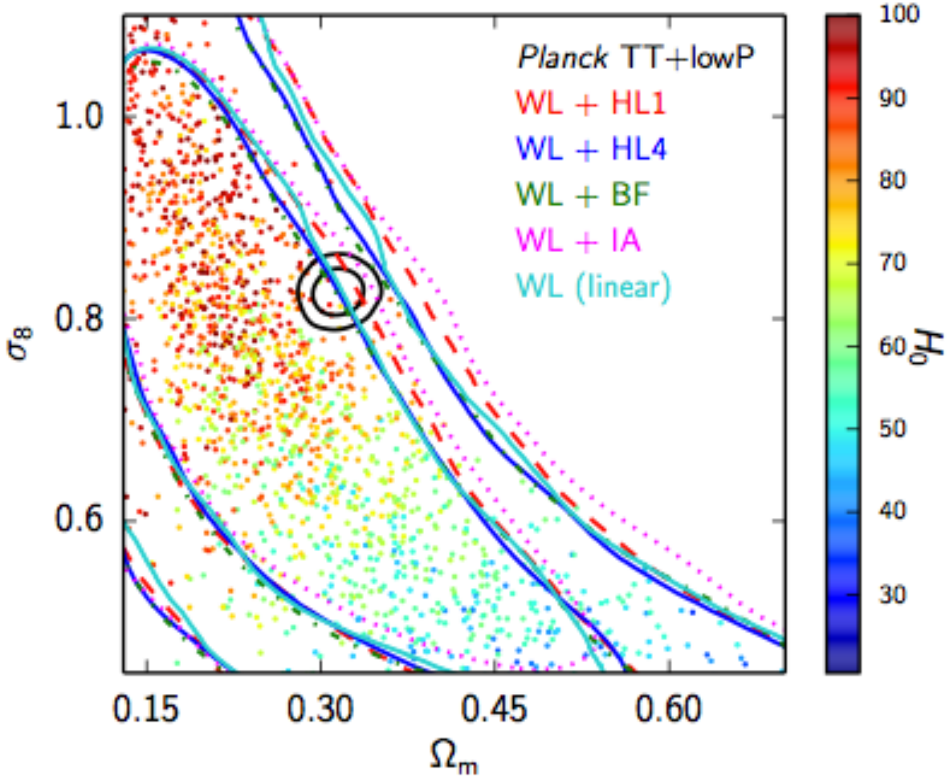
Harnois-Deraps et al. 2014

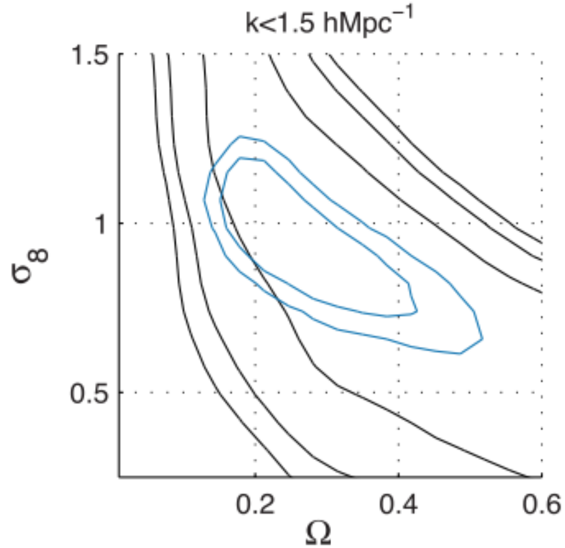


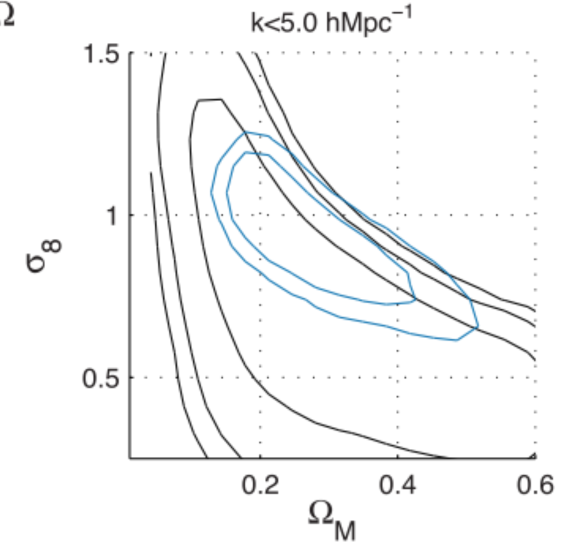
Biases at small scales?

Planck 2015

Kitching et al. 2014



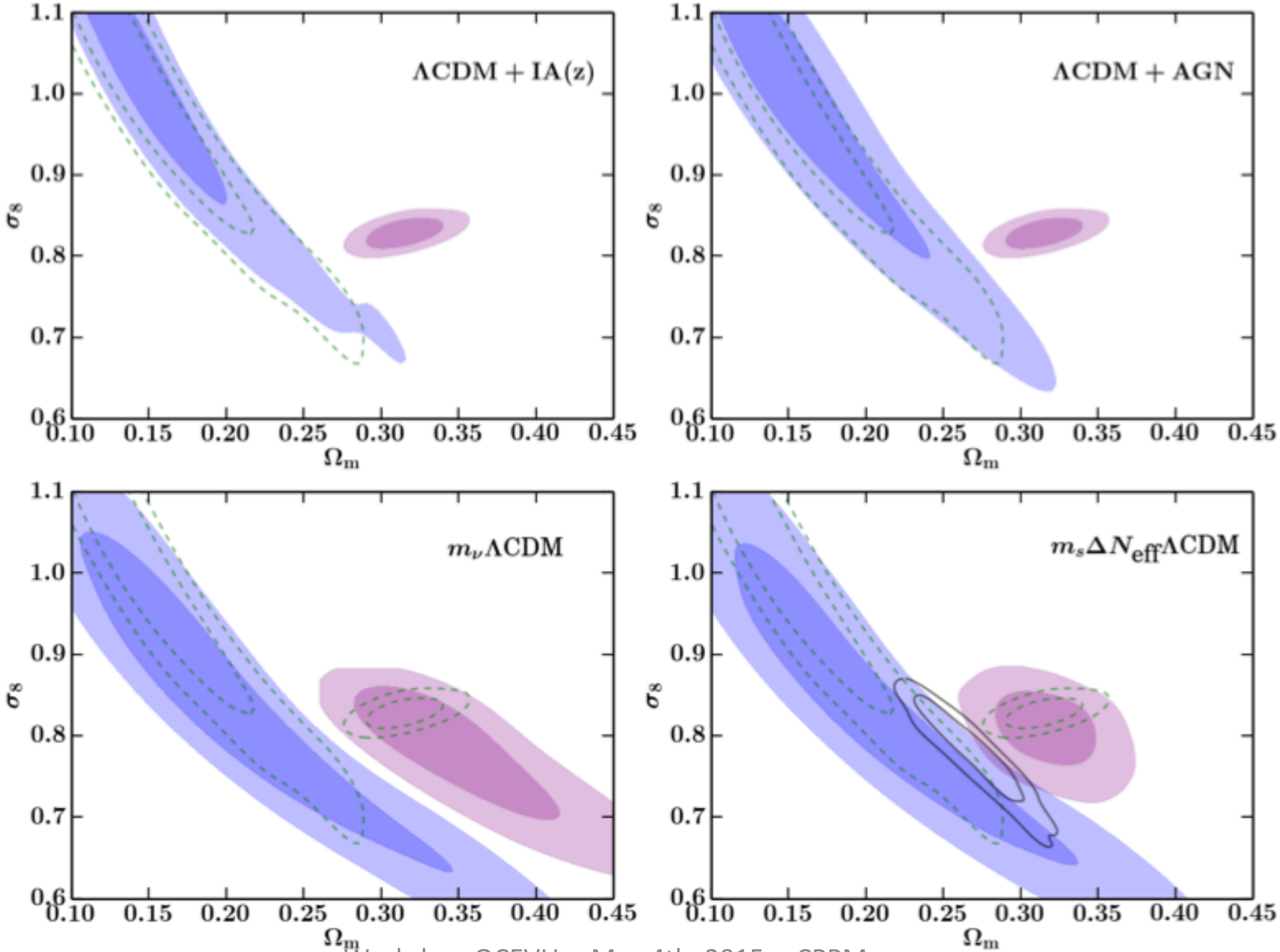




➔ Dependence on the small scale cut

Other WL biases?

MacCrann et al. 2014



So…

- There is still a tension between WL and CMB+BSH

- The tension seems to come from small scales
  - ➔ Smaller scales prefer larger σ_8, thus smaller Ω_M
  - ➔ Astrophysics systematic error
  - ➔ Hint for modified gravity?

- but is not explained by currently known systematics on WL

Weak lensing/Imaging surveys

Existing datasets

- CFHTLens (154deg^2) and CFHT-Stripe82 (130deg^2 eff.)
- Planck Lensing (full sky low resolution)

Forthcoming

- KIDS (1000deg^2), part is available. Overlap with VIDEO in the NIR.
- DES (5000deg^2) *griz* public raw images. Need to reduce and measure shapes
- DECALS (6700deg^2) in *grz*. Images public and reduced by March 2015. Need to measure shapes

Future

- Euclid (15000deg^2)
- LSST

Clustering Data with access

Existing

- VIPERS (24deg^2), BOSS (10000deg^2), WiggleZ?

Forthcoming

- eBOSS (1500deg^2 ELG $0.6<z<1.0$, 7500deg^2 LRG $0.6<0.9$, and QSO $0.9<z<2.2$)

Future

- PFS, DESI, Euclid (mostly ELG galaxies, their clustering model is still pooly known)

Our project in the Labex

- Combine WL from CFHTLens and CFHT-Stripe 82 with PV from ~300,000 BOSS CMASS and ~100,000 VIPERS galaxies
- We will use the ϒ(R) operator to get rid of small scales

$$\Upsilon_{\mathrm{gm}}(R) \equiv \Delta\Sigma_{\mathrm{gm}}(R) - \left(\frac{R_0}{R}\right)^2 \Delta\Sigma_{\mathrm{gm}}(R_0)$$

$$\Upsilon_{\mathrm{gg}}(R) \equiv \rho_c \left[\frac{2}{R^2} \int_{R_0}^{R} \mathrm{d}R' \, R' \, w_{\mathrm{gg}}(R') - w_{\mathrm{gg}}(R) + \left(\frac{R_0}{R}\right)^2 w_{\mathrm{gg}}(R_0) \right]$$

- We will use the MultidarkLens Simulations to quantify the amount of systematic errors and compute covariance matrices

BOSS/CFHTLS/STRIPE82 overlap

Surface (deg)^2	CMASS Z>0.43 Galaxies	Galaxies weighted	Random	Random weighted	LOWZ Z<0.43 Galaxies	Galaxies weighted	Random	Random weighted
W1 63.8	4067	870.6	218183	43230.4	2352	300.6	133731	16357.3
W3 44.2	3142	620.2	146970	28779.4	1596	218.0	77258	10307.6
W4 23.3	1760	394.1	91498	18135.7	957	120.9	55676	6811.5
stripe82 10	14288	2878.8	678653	134593.6	8610	1086.6	410079	50081.9

For VIPERS/CFHTLS → 100% overlap → ~100000 spec-z galaxies

MultidarkLens

- Sim. DM-only with Planck cosmology (Ω_m = 0.31)
- 2.5 Gpc/h periodic box and 3840^3 particles
- Mass range of halos 4.7×10^{11} to 6×10^{15} Msun/h
- Halo catalogs extracted with FoF

➔ Available at the multidark database

http://www.multidark.org/MultiDark/Help?page=simulations

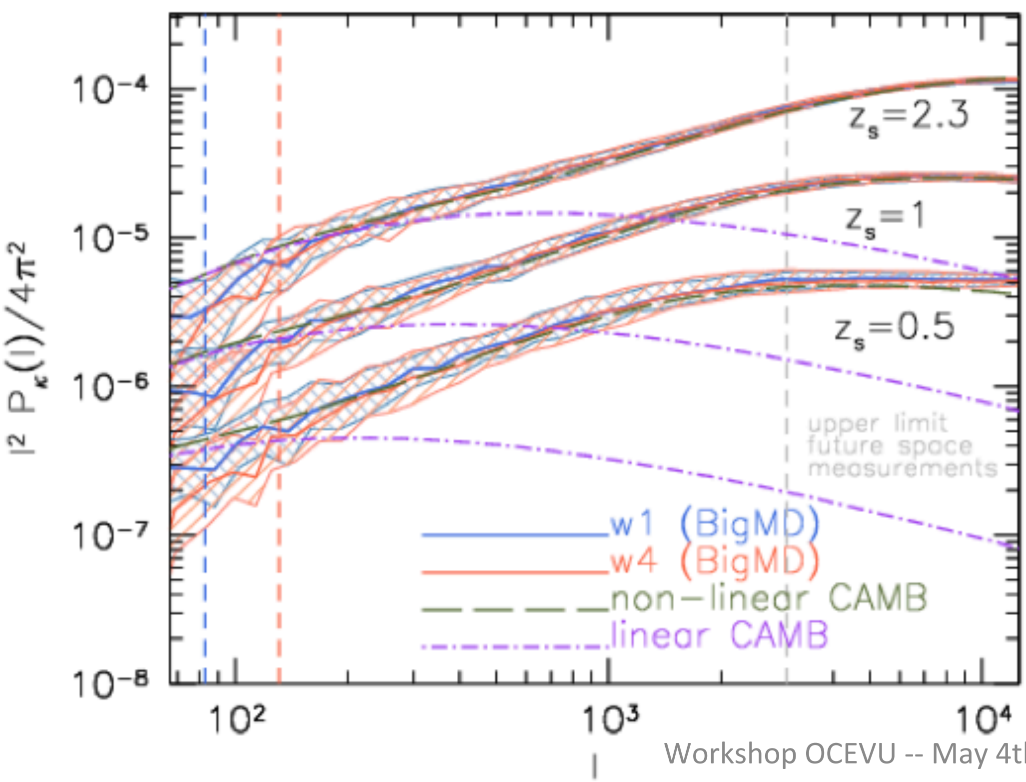
- Lensing lightcones done over ~400deg^2 from $0 < z < 2.3$
- Limiting resolution 0.6 arcmin (~240kpc at z=0.5)

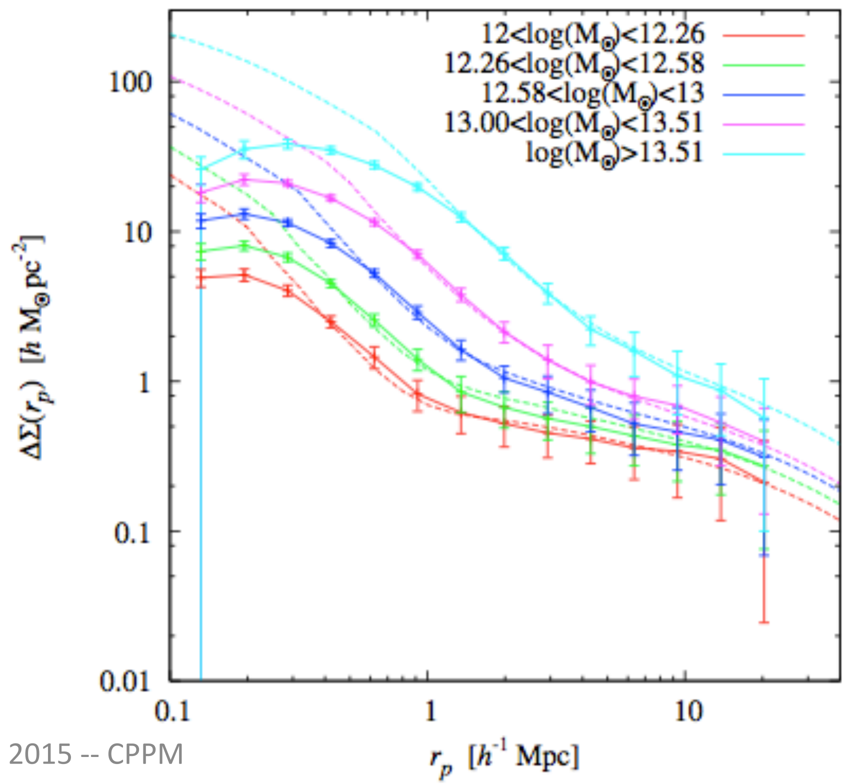
➔ Soon available at the BolognaLensFactory

https://bolognalensfactory.wordpress.com/

MultidarkLens Quality checks

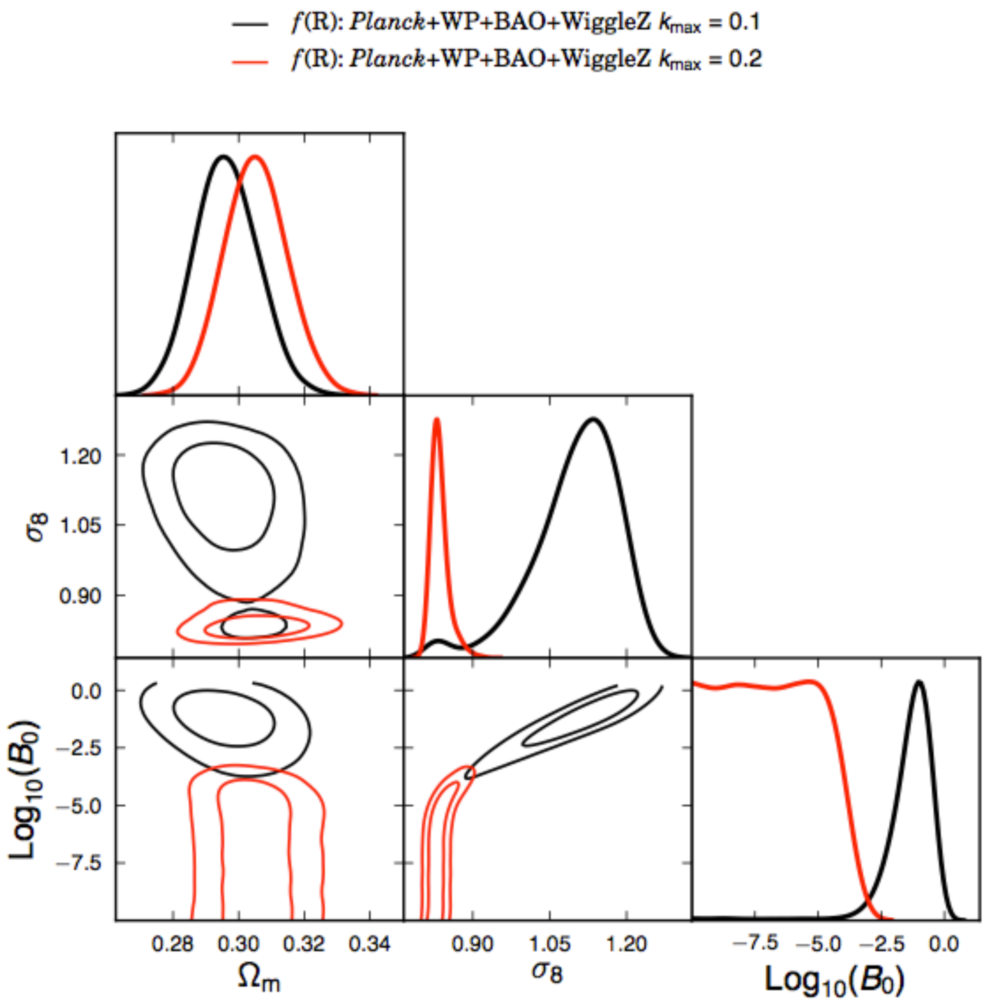
- Checks on cosmic shear measurements
- Checks on halo and galaxy-galaxy lensing





Updates with Planck data

Dossett et al. 2014



- For k < 0.1/Mpc, the power spectra data prefer a smaller value of Ω_M thus a higher value of σ_8 and a higher B_0.
- For k < 0.2/Mpc,